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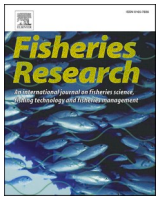

# Conservation for sustaining livelihoods: Adaptive co-management of fish no-take zones in the Mekong River

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ABSTRACT

A major challenge in natural resource management in developing countries is to pursue conservation objectives while avoiding negative impacts on local livelihoods. Inland capture fisheries provide opportunities to demonstrate an integration of conservation and livelihood objectives when managed as a social-ecological system. While numerous marine no-take reserves have been found effective for the recovery of fisheries, few well-documented examples exist in the freshwater realm. Research gaps also remain in the role of co-management in balancing various management objectives and resolving conflicts. This paper offers critical reflection on adaptive co-management of fish conservation zones (FCZs) in the Mekong River in Cambodia and its social-ecological outcomes as perceived by local stakeholders. The management approach was found generally effective for the local stakeholders to negotiate between conservation and livelihood objectives at key stages of the implementation, and resolve conflicts; however, the lessons learned were not uniform across all sites. The degree of difficulty in conflict resolution was mainly a function of the fishing dependency of local communities on the protected site, the prevalence of severe poverty in adjacent villages, and the availability of livelihood options other than fishing. Growing stakeholder perception over time, of the FCZs as yielding positive outcomes—for both conservation and livelihood—motivated the local communities to create more FCZs. We argue clear recognition by local stakeholders of the achievements and the fairness in the FCZ management, facilitated through participatory approaches, can improve their acceptance of conservation rules and enhance their effectiveness. However, long-term mechanisms to support these community initiatives technically and financially are needed. Simple yet scientifically robust approaches for tropical freshwater fisheries monitoring, including periodical assessments of indicator species, are also needed to facilitate performance evaluation of specific management measures locally.

## 1. Introduction

A major challenge in natural resource management in developing countries is to pursue conservation objectives while avoiding negative impacts on local livelihoods. Capture fisheries, primarily an exploitation of wild animals for human utilization, is a key provisioning service derived from healthy aquatic ecosystems (MEA (Millennium Ecosystem Assessment), 2005). Inland water ecosystems yield 11–14 million metric tons of wild capture fisheries each year, contributing to the livelihoods of over 60 million people in developing countries (Mills et al., 2011). Hence their management provides opportunities for integrating conservation and livelihood objectives, when managed as a social-ecological system where resources and resource users are both considered part of resource management planning and implementation (Berkes et al., 2003).

In the context of small-scale fisheries management in developing countries, practical application of the social-ecological systems concept is found in area-based resource conservation through protected areas (e.g., Pollnac et al., 2010), and stakeholder engagement through co-management (e.g., Pomeroy et al., 2011). The former emphasizes the

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integration of broad ecological principles into conservation of target fishery, while the latter emphasizes the governance and equity aspect of fisheries management. Over time both approaches have converged towards an integrated set of management objectives to benefit a variety of stakeholders, and have faced challenges in balancing multiple objectives.

No-take marine reserves offer a relatively simple, cost-effective option for regulating complex tropical small-scale fisheries in developing countries, where limited scientific knowledge and local capacity preclude conventional measures, such as licensing and catch quotas (Kura et al., 2004; Selig et al., 2016). Numerous studies on no-take marine reserves reported positive outcomes for biomass, species richness, and size of organisms within the reserves (Lester et al., 2009; Babcock et al., 2010), and "spillover effect" into fisheries in adjacent waters, despite a bias towards sedentary species in rocky shores or coral reef systems (Halpern et al., 2010; Di Lorenzo et al., 2016).

Contrary to its marine counterparts, very few well-documented examples of effective fisheries conservation through freshwater protected areas (FPAs) exist, especially in developing countries (Butorac et al., 2020; Loury et al., 2018). The paucity of well-documented examples may have to do with the unique challenge freshwater ecosystems face. The efficacy of FPAs in migratory fish conservation is challenges by their inability to ensure habitat connectivity and regulate human activities at the catchment basin scale (Bower et al., 2015), notably fishing and the use of water to meet human needs (Acreman et al., 2020). The difficulty in conducting monitoring and evaluation studies of FPAs was also noted (Acreman et al., 2020), especially with regards to tropical inland fisheries (Elliott et al., 2019).

The shortage of empirical evidence should not be translated as the lack of potential, however; studies on the role of habitat conservation in inland fisheries management have shown some promise, in Lao PDR (Baird and Flaherty, 2005; Butorac et al., 2020), Cambodia (Fiorella et al., 2019; Freed et al., 2020), India (Sarkar et al., 2012), and Brazil (Keppeler et al., 2016). These freshwater examples are found in large tropical rivers and associated seasonal floodplain systems, home to highly diverse fish species assemblages comparable to those in tropical coastal fisheries (e.g. over 1200 species in the Amazon and 780 in the Mekong, recorded in Froese and Pauly, 2019). Most fish species in these ecosystems are known to undertake lateral or longitudinal migrations at least once in their life cycle. Compared to the species assessed in marine reserve studies, however, scientific knowledge on the biology and the lifecycle of freshwater fish in the tropics is limited (Bower et al., 2015; Revenga and Kura, 2003).

While significant research effort has been devoted to "rational" identification of suitable location and design of freshwater or marine reserves in data-poor social-ecological systems (e.g. Ban et al., 2013; Gaines et al., 2010; Nel et al., 2009), the actual implementation of the reserves has proven difficult (Selig et al., 2016). In reality, balancing conservation and poverty alleviation in the context of protected areas requires trade-offs (McShane et al., 2011) and negotiation among environmental, economic, and social objectives with resource user involvement (Pomeroy and Douvere, 2008).

In addressing this complex challenge, co-management—the sharing of authority and responsibility between state and resource users in the management of common-pool resources—emerged as a governance regime in which specific fishing regulations can be applied (Ratner et al., 2012). Several contextual and procedural attributes of fisheries co-management have been associated with positive outcomes (Evans et al., 2011; Gutiérrez et al., 2011; d'Armengol et al., 2018). Research gaps remain, however, in clear articulation of how well co-management can balance and sustain management objectives, negotiate conflicting interests, and sustain positive outcomes long-term (d'Armengol et al., 2018).

In practice co-management takes on a variety of forms (Cohen and Steenbergen, 2015; Cohen and Roscher, 2021), is a process not a fixed state (Carlsson and Berkes, 2005), and therefore cannot be treated as panacea for addressing the inherent complexity in various social-ecological systems (Ostrom and Cox, 2010). Adaptive co-management (ACM) takes the concept of managing social-ecological systems further by integrating experiential learning into co-management (Plummer et al., 2012). Key process attributes of ACM, namely collaboration among stakeholders and collective learning, were associated with positive outcomes in conservation (Plummer et al., 2017); however, more empirical studies are needed to illustrate the causal linkages and guide future program design.

This paper describes the process and outcomes of adaptive co-management of fish conservation zones (FCZs) from 2011 to 2017, in a section of the Mekong River in Cambodia. We offer critical reflection on the approaches and their outcomes from the perspective of resource management practitioners. From this case study, we aim to fill the research gaps in the role of FCZs and adaptive co-management in the freshwater realm. We explore the following questions:

- In what ways did local communities integrate social and ecological considerations into their decision-making and resolve conflicts through the adaptive co-management of FCZs;
- What constrained or motivated local communities to prioritize conservation over their livelihoods in some situations, while not in others;
- What positive and negative outcomes of FCZs were perceived by local communities in some situations, while not in others; and
- What are the key lessons for long-term implementation of FCZs.

## 2. Background

Cambodia is home to the 5th most productive inland fisheries in the world, despite its relatively small area (Funge-Smith, 2018). Wild fish catch from its rivers, lakes and floodplains reaches 500,000 metric tons annually (Fisheries Administration, 2017). The fisheries sector in Cambodia experienced dramatic changes since the government began sector reforms in 2001, during which "fishing lots", or private concessions operated under state-run auctions to manage and exploit inland fisheries, were gradually abolished (e.g. *Sub-Decree No. 10, 2001,* and *Sub-Decree No. 37, 2012, on Abolishing Fishing Lots)*.

As part of the transboundary Mekong River System, inland fisheries in Cambodia, and the livelihoods and food security of those who depend on the fisheries, are influenced by the rapid water development taking place in the region, most notably hydropower and irrigation (Chua et al., 2022; Golden et al., 2019). Fisheries monitoring programs have been implemented only since the early 2000s with a limited geographic scope, making it difficult to assess the resource status and the influence of various factors, including policy changes, to the resources (Mekong River Commission, 2021). According to the few studies that exist, however, regional experts generally agreed that the overall quality of the catch declined—characterized by the reduction in large-bodied, migratory, and/or predatory species—while the total biomass remained stable (Chan et al., 2020; Ngor et al., 2018).

In support of the sector reforms since 2001, the Fisheries Administration (FiA) of the Cambodian government gradually established over 500 community-based fisheries organizations called Community Fisheries (CFi), mandated with the management and sustainable use of fisheries for subsistence (*Sub-Decree No. 80 on Community Fisheries Management* 2005). Through a system of co-management with the government agencies and local authorities at various levels, the CFi groups around the country have implemented several area-based resource management measures as defined by individual CFi's internal rules and by-laws, set in line with the existing *Fisheries Law* (2006) (Fisheries Administration, 2018; Kaing et al., 2021).

Most common activities led by CFi were the patrolling against the use of illegal, destructive fishing gear (e.g. electro fishing, dynamite, fine-mesh nets) and the creation of a conservation area or fish sanctuaries within their designated management area (Kurien, 2018). However, the

level of implementation varied; the institutional and financial sustainability of CFi management committees was found to be particularly weak (Ly, 2018). Local fishing communities, at individual level, had mixed perception of the reform's benefits thus far (KC et al., 2020).

Several area-based conservation approaches have been employed in Cambodia with different governance regimes and degrees of fish conservation, called protected areas, fish sanctuaries, refuges, or critical habitats (Fisheries Administration, 2010). For the purpose of this study, we call the management areas established by the local communities for the purpose of fish conservation as fish conservation zones (FCZs). The

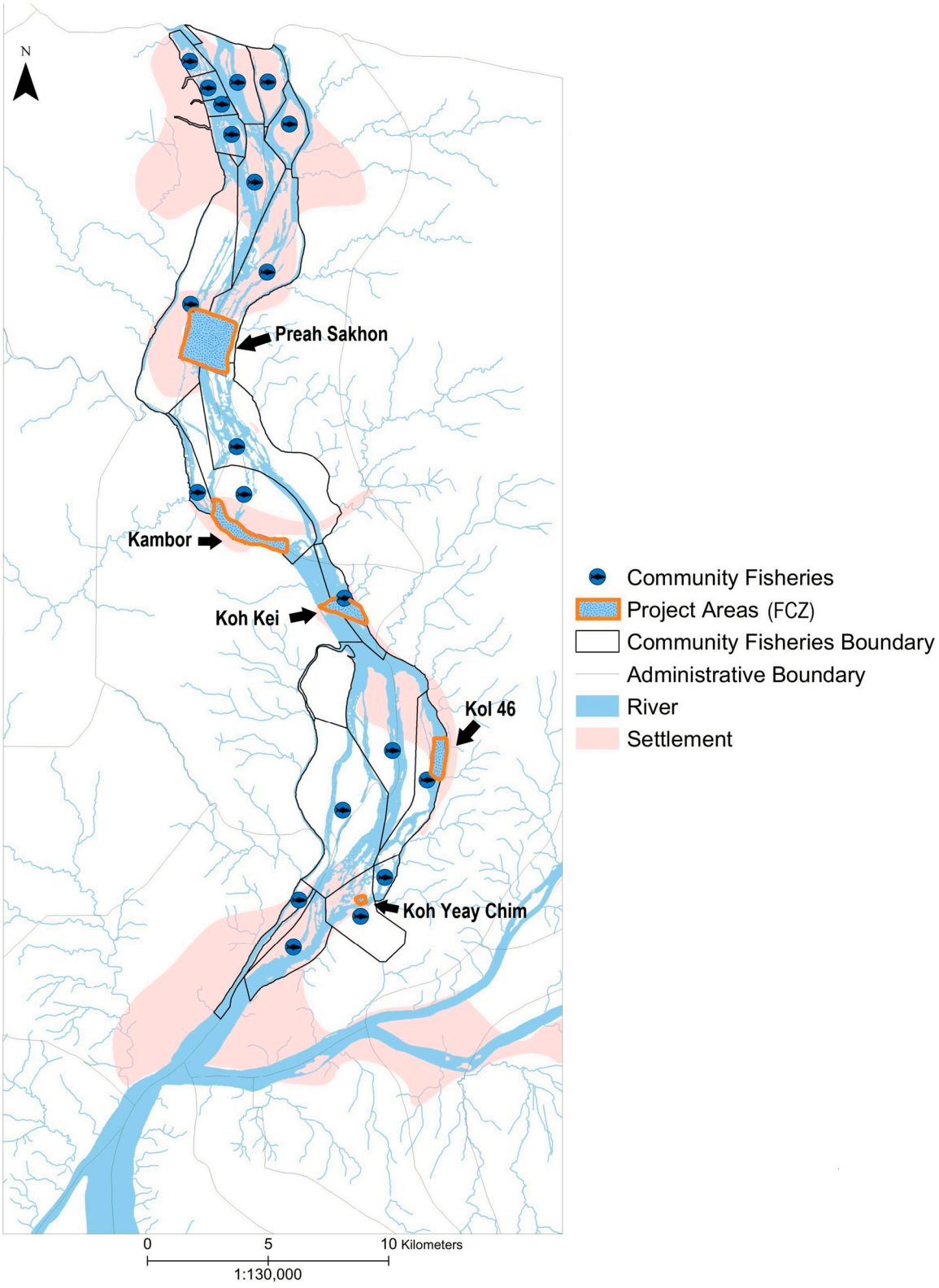


**Fig. 1.** Map of project site in the Stung Treng Ramsar site in Northeast Cambodia. FCZ boundaries are approximate and do not reflect the exact shape and the size of the FCZs.

term FCZs has been used in reference to the community-based conservation of deep pools within the Mekong River and its tributaries in Lao PDR since the 1990s. Where and how exactly an FCZ is established and managed depends on the location and is typically decided by the local community in consultation with other parties to co-management (Baird, 2006; Butorac, 2020). Our project site in Cambodia shared similarities to the riverine fisheries in Lao PDR.

## 3. Methods

### 3.1. Study site

Our project site was a section of the Mekong River in Northeast Cambodia near the border with Lao PDR (Fig. 1). It had been designated as a "wetland of international importance" by the Ramsar Convention on Wetlands (2005) under the direct management of the Stung Treng Provincial Department of Environment (DoE). The Ramsar site was 146 $km^2$ in size and consisted of braided river channels, islets, inundated forests, and hosted many "deep pools"—areas of river bed significantly deeper than the surrounding areas and held water during dry season, some as deep as 70 m (Chan et al., 2004). The deep pools provided refuges for fish in dry season when the water levels were shallow in other parts of the river channel. Home to an endangered population of Irrawaddy dolphins (*Orcaella brevirostris*), the entire area also acted as a major fish migration corridor within the Mekong River system and provided spawning grounds for commercially-important fish species (Allen et al., 2008).

Inhabited by more than 12,000 people in 21 villages, the Ramsar site supported local farming and fishing livelihoods that were strongly connected to seasonal flows and flood patterns of the Mekong River. A stakeholder analysis of the project (2012) placed most of the households in either "poor" or "very poor" categories, characterized by primarily subsistence livelihoods, low ownership of productive assets, namely farmland, livestock, and motorized boats, and a rice deficit of 3–7 months each year. The main sources of cash income were fishing, wildlife hunting, and selling farm labor. Regardless of their wealth status, households in these remote villages lacked access to basic infrastructure, social services, and markets.

Lack of local capacity and coherence in external assistance had hindered the implementation of conservation activities in the Ramsar site. With support from various non-governmental organizations (NGOs), 17 CFi groups had been established within the Ramsar site; however, prior to 2011 when our project started, many were inactive. Signs of distress in the social-ecological system had been widely reported—environmental degradation and declining fish stocks, increase in illegal and destructive fishing, and conflict among the resource users.

With the combination of rich natural resources and highly resource-dependent local communities, the site held a strong potential for demonstrating the benefits of conservation for local livelihoods. The site was well suited for introducing experimental fisheries conservation measures through the existing co-management institutions. It met or partially met each of the "ten conditions for successful adaptive co-management" as outlined in Armitage et al. (2009), in particular: identifiable set of social entities with shared interests; access to adaptable portfolio of management measures; and key leaders prepared to champion the process.

### 3.2. Adaptive co-management process

We followed the principles and process of adaptive management, namely flexible institutional arrangements that were regularly reviewed and adjusted based on shared reflection and learning by the participants (Armitage et al., 2009), and a simple cycle of implementation (detailed by Parks, 2011): 1) develop a plan; 2) take action; 3) evaluate progress; 4) adjust future action; and 5) repeat the cycle. Fig. 2 shows our project timeline from 2011 to 2017. During this period, the project supported 4 cycles of adaptive management process.

With facilitation provided by researchers, the local CFi representatives led planning, decision-making, and on-site implementation, with technical assistance from the provincial DoE and FiA, and local NGOs. Site-specific co-management arrangements and rules were made in line with the existing laws and guidelines, and with endorsement of local government authorities at district, commune, and village levels. These co-management actors shared a clear objective; recovery of fisheries resources through conservation measures.

The project began in April 2011. The implementation of the first 3 FCZs started in April 2012, followed by the first reflection workshop in June 2012 to gather initial feedback. The second and the third workshops took place every six months thereafter, then the fourth workshop in April 2014, nearly one year after the third workshop. The FCZ management committees revised respective management plans at the end of each calendar year, based on the results of the reflection workshops as well as other monitoring activities (Table 1). Minor adjustments in activities, such as patrolling regime, were made as needed. After an evaluation of the first 3 years, the project entered its second phase in mid-2014, adding 2 new FCZs to the portfolio as decided by the local stakeholders at the end of the second cycle of the adaptive management.

We applied participatory approaches to planning, decision-making, and monitoring, involving as many stakeholders as feasible so that they could contribute individually or collectively throughout the process. The stakeholders were identified for the entire Ramsar site and at each of the proposed FCZs, and their involvement in various stages of the project implementation was ensured as part of the social safeguard strategy of the project (WorldFish, 2011, and subsequent annual updates in 2012–2016). Engagement of poor, marginalized households in decision-making was particularly important for avoiding or mitigating negative impacts of the project on them and was ensured through key informant interviews (KII) of those who could not afford to participate in

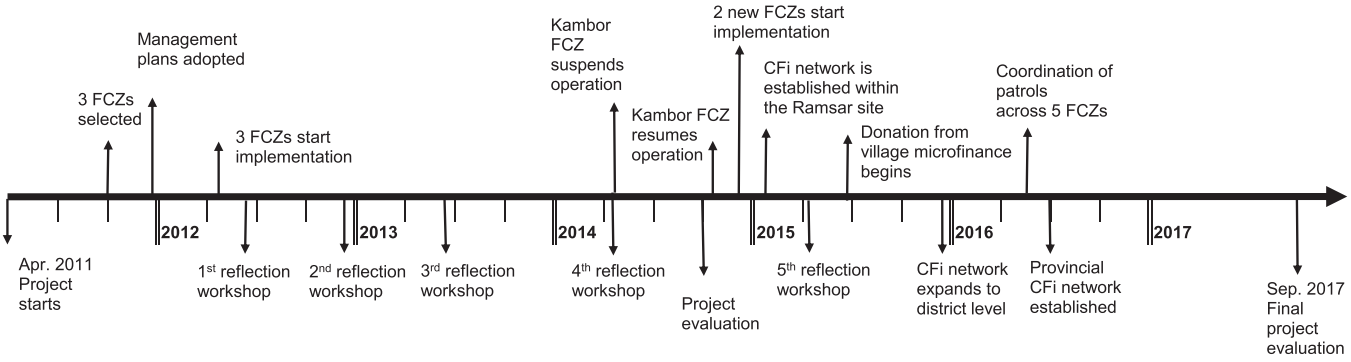


**Fig. 2.** Project timeline 2011–2017. It shows the cycle of adaptive management, including key events and management changes over the course of the project implementation.

**Table 1**
Summary of the data gathering methods, frequency, types of participants, and information collected.

| Methods | Frequency | Number of participants | Type of participants | Information collected | Sources/project documents |
|---|---|---|---|---|---|
| FCZ committee meetings | Monthly | 10–20/FCZ | CFi committee members, village chiefs, commune council members, DOE rangers. | Progress in activities, number of patrols, sighting of illegal fishers | CFi activity reports to FiA |
| Focus group discussions | Every 6 months | 5–10/group | Local fishers, poor households, those considered vulnerable to the negative project impact. | Perceived fisheries status, livelihoods impacts, adequacy of social safeguards. | Social Safeguard Strategy Updates (Jun. 2012, Feb. & Jun. 2013, Feb. 2014, Feb. & Jul. 2015, Jan. & Jun. 2016) |
| Key informant interviews | Every 6 months | 10–15/FCZ | Women-headed and/or poor families, seasonal migrant fishers, fish traders. | Perceived fisheries status, livelihoods impacts, adequacy of social safeguards. | KII notes (Jan. & Nov. 2012, Mar. 2013, Jun. & Oct. 2014, Mar. 2015, Jan. & Aug. 2016, Jan. & Aug. 2017) |
| Reflection workshops | Every 6–12 months | 40–50 | CFi members, village chiefs, commune council, DOE, FiA, local NGOs. | Achievements, innovations, challenges, planned responses. | Reports of the reflection workshops (June & Dec. 2012, May 2013, Apr. 2014, May 2015) |
| Fish catch monitoring (log sheets) | Monthly | 21 (2012–2013) to 42 (2014–2015) | Fishers active in buffer area of FCZs or nearby fishing grounds. | Daily catch quantity by fish species (groups) and by gear type per fisher. | Fish catch monitoring summary reports (2013, 2017) and databases |

The data were collected for the first 3 FCZs for the period 2012–2017, and for the 2 additional FCZs for the period 2014–2017.

village meetings or focus group discussions (FGD). Local community members contributed their time and resources to the FCZ management and monitoring activities on a voluntary basis. The project provided no monetary compensation to the local participants.

More specifically, a participatory action research (PAR) method was used to monitor and assess the progress and the outcomes of the project, as part of adaptive management. It constituted a repeated cycle of joint reflection and learning, involving local community members and other key stakeholders (Apgar et al., 2017). The researchers facilitated group reflections at village meetings and reflection workshops, addressing what worked well, what did not work well and why, and what adjustments were needed. The facilitators were either employees or consultants of WorldFish or the local partner NGOs, both Cambodian nationals and expatriates, who were directly involved in the project.

### 3.3. Data collection

#### 3.3.1. Qualitative survey of stakeholder perception

Our primary source of information was qualitative surveys of stakeholder perceptions, compiled in reports and notes from village meetings, provincial workshops, FGDs, and KIIs (Table 1). Many of the interviewees were the members of CFi committees, village chiefs, and commune council members—all elected positions—representing 14 out of the total 21 villages located within the Ramsar site. We purposefully selected other interviewees from these 14 villages (total population of 6459 in 2011) based on each activity. For example, the participants in FGDs on fisheries resource status were “knowledgeable" fishers, who had several years of experience fishing in and around an FCZ. The households categorized as relatively poor during wealth ranking or as vulnerable to negative impact of FCZ were interviewed about livelihood impacts of the project.

Sampling pool of participants in various FGDs and KIIs by categories (not necessarily mutually exclusive) were: CFi committee members (n = 98); village chiefs (n = 14); knowledgeable fishers (n = 62); fishers involved in catch monitoring (n = 42); fish traders (n = 10); poor households eligible for social safeguards (n = 106); and seasonal migrant fisher households (n = 30). For each FGD or KII event we interviewed 5–15 individuals randomly selected from these stakeholder categories for each of the FCZs. Cumulative number of participants over the course of 6 years was 306, although many individuals were likely interviewed multiple times. Additionally, we held reflection workshops five times, each with 40–50 participants representing the 14 villages and local authorities involved in the project, where the FGD and KII results were validated according to PAR (*described in* Section 3.2.).

While every effort was made to maintain objectivity in the data collected by the project staff, the self-evaluation of local participants required careful treatment. Consultants and donor representatives who were not directly involved in the project periodically conducted project evaluation (Schofield, 2013; Honoré, 2016; Doheny, 2017; Estepa, 2017). The findings of the evaluation improved objectivity in the interpretation of the data collected by the project team.

#### 3.3.2. Fish catch records

We collected records of daily fish catch by individual fishers from 2012 to 2015. The purpose of the data collection was to test whether fisher perception documented in qualitative surveys can be verified with the fish catch records. We recruited and trained local fishers to record the weight of their own fish catch daily, by type of fish, in monthly log sheets. Each fisher used different set of mixed active and passive gear—set gillnet, hook and line, cast net, and various bamboo traps—depending on the time of year. The fishing effort, in terms of the type and the number of gears, was restricted to the level considered as “subsistence fishing” by the government regulation. It was not intended for assessing catch per unit effort (CPUE) of each fisher or a gear. The project staff collected the log sheets monthly, checked omissions, corrected errors in hand-written records, and verified outliers with the fishers who recorded those.

Through our project monitoring, a total of 90 valid daily catch records were collected from August 2012 to May 2013 (by 21 fishers at the Kol 46 and Kambor FCZs only), and 1876 records were collected from August 2014 to June 2015 (42 fishers at all 5 FCZs). Much fewer records were available for 2012–2013 because of frequent omissions in, and physical damages to the paper records; however, reporting of catch by species was detailed in the valid samples. The fishers received additional training and recorded their daily catch more consistently in 2014–2015, with disaggregated catch data for up to 5 species each day. There was a gap in the monitoring between May 2013 and August 2014 due to a project funding gap. The catch monitoring ceased after June 2015 because many fishers wished to discontinue cumbersome recording of their daily catch without monetary compensation from the project. Summary statistics of the fish catch data was generated in SPSS (2007). We also tested the difference in the distribution of daily catch quantity by fisher between the periods 2012–2013 and 2014–2015 using Mann-Whitney independent sample test (SPSS, 2007).

Assessing the condition of fisheries resources was never the purpose of this data collection. The catch records of small number of fishermen, for a limited time period, were clearly insufficient for assessing the abundance and the yield of the highly diverse, seasonally dynamic, and annually fluctuating fisheries of the Mekong River, as noted previously (Elliott et al., 2019; Halls and Hortle, 2021). The temporal and geographic coverages of existing fisheries monitoring programs (Halls, 2013; Mekong River Commission, 2021) were limited and did not

sufficiently cover our project site. Participatory monitoring approaches, including fisher perceptions, have been historically adopted and widely accepted in the region by the Mekong River Commission and the local governments to complement the existing data (Halls et al., 2013; Elliott et al., 2019).

## 4. Results

### 4.1. Integration of social and ecological information during FCZ site selection

A first set of 3 FCZs (*Kol 46, Kambor, Preah Sakhon*) was selected in December 2011. The local communities selected these sites through a series of workshops and consultation meetings facilitated by the project team over a 4-month period prior to the final decision. In absence of detailed biophysical information within the Ramsar site, the FCZ selection relied on the knowledge of local fishers. First, a set of criteria for the site selection was agreed among the stakeholders, including both ecological and social factors. Second, the community representatives nominated around a dozen candidate sites, and then shortlisted 5 sites after group discussions. The 5 sites were then scored and ranked by 35 knowledgeable fishers representing 14 villages according to the criteria. Each criterion was scored in the range of 1–5. Some criteria, such as the presence of fish spawning grounds and dry season refuges, were considered critically important by the participants, and given multiplication factors to increase weight in the overall score (Table 2).

The final selection was then made through consultation meetings with the local fishers who frequented the candidate sites for fishing, and based on the following factors: the willingness of local villagers to serve as the stewards of the FCZ; the potential negative impact of restricting access to the site on local livelihoods; and the availability of alternative fishing grounds. One site (*O'talas*) was rejected due to the inaccessibility of the area for regular patrolling and the lack of permanent human settlements nearby. Another site (*Koh Traeng*) was rejected due to the objection from a local village that heavily relied on this site for fishing and did not have alternative fishing grounds nearby.

Conversely, another site was selected because the local villagers expressed strong willingness to protect it (*Kol 46*). They saw the potential benefits of fisheries recovery by designating this deep pool as an FCZ. Several other villages decided to take on the challenge of protecting an ecologically important but large and remote site, emboldened by the technical and financial support available from the project to facilitate its establishment as an FCZ. It was decided that *Preah Sakhon* be jointly managed by 5 CFi groups—an endeavor never attempted previously in Cambodia. The site encompassed vast inundated forests in the center of the Mekong River and was known as a spawning ground for *trey riel* (consisting mainly of *Henicorhynchus siamensis*), small migratory fish that was considered most important for local food security and livelihood. The local villagers saw the potential benefit of protecting *Preah Sakhon* as overwhelmingly higher than the effort required to protect it (the project workshop report, 2011).

Potential negative impact of FCZs on local livelihoods was a defining factor of "no go" decisions. It seemed the first 3 sites struck a balance between conservation and livelihood concerns because they were geographically dispersed from each other and other productive fishing grounds were still available for local users (WorldFish, 2013). Two years later in 2014 the local stakeholders decided to add 2 new FCZs (*Koh Kei* and *Koh Yeay Chim*), having determined that the long-term benefits of creating FCZs would exceed the initial cost of fishing closure to local livelihoods (the project workshop report, 2014). By 2016 they formed a network of the 5 FCZs (Table 3, Fig. 1) and started coordinating patrolling of the waters in-between the FCZs to enhance conservation (WorldFish, 2016a).

### 4.2. Adjusting FCZ boundaries to accommodate the needs of poor and vulnerable households

Having considered several regulatory measures for fishing activities at each site, such as gear restriction, species and/or size-selective fishing, and temporary closures, the local communities chose to designate the FCZs as permanent no-take zones. A clear advantage of this approach from their perspective was the relative ease of enforcement. This strategy also did not conflict with existing provisions under the *Fisheries Law* (2006) of Cambodia. By April 2012, all 3 FCZs became operational.

In a short to medium-term, the main social concern was to avoid negative impacts of FCZs on the poor and vulnerable households among the local communities, who had been identified through stakeholder analysis. During the FCZ boundary negotiation, buffer zones were established at the two of the FCZs as a social safeguard for the most vulnerable households—residing next to the FCZ and with no means of traveling to alternative fishing grounds. These households were named in the site-specific management plans and given preferential access to the buffer zone for subsistence fishing using prescribed gear. In return, they guarded the no-take zone and alerted the patrol team of illegal fishing activities (*Management Plans for Kol 46 and Kambor FCZs, 2012–2015*). *Preah Sakhon* FCZ did not establish such a buffer zone as there was no permanent human settlement adjacent to the site.

The safeguard strategy was generally effective for the *Kol 46* FCZ but not sufficient for the *Kambor* FCZ. In April 2014—two years after the FCZ started—the *Kambor* FCZ management committee decided to suspend its operation because a local village was divided in opinion between those who supported the FCZ and those who did not. This village

**Table 2**
Fish conservation zone (FCZ) selection criteria and the scores for the 5 shortlisted candidate sites.

| Criteria | Site name | | | | |
|---|---|---|---|---|---|
| | *Kol 46* | *Kambor* | *Koh Traeng* | *O'talas* | *Preah Sakhon* |
| High species biodiversity | 3 | 2 | 1 | 5 | 4 |
| Fish spawning ground (x3) | 9 | 9 | 6 | 15 | 15 |
| Abundance of fish for livelihood (x2) | 8 | 6 | 6 | 10 | 10 |
| Plant species for herbs/ medicine | 2 | 2 | 1 | 3 | 1 |
| Habitat for endangered species (x2) | 6 | 6 | 4 | 8 | 6 |
| Local Community Fisheries (CFi) is active (x2) | 2 | 2 | 2 | 2 | 2 |
| Accessibility | 2 | 4 | 4 | 1 | 2 |
| Refuge for fish in dry season (x3) | 12 | 15 | 15 | 9 | 9 |
| Sufficiently large area of water | 4 | 5 | 5 | 4 | 5 |
| **Total score** | 48 | 51 | 44 | 57 | 54 |

Each criterion was scored 1–5. Some criteria were given multiplication factors to increase weight in the total score.
Sources: project workshop reports, 2011.

**Table 3**
Five fish conservation zones (FCZs) supported by the project.

| Site name | *Kol 46* | *Kambor* | *Preah Sakhon* | *Koh Kei* | *Koh Yeay Chim* |
|---|---|---|---|---|---|
| Main habitat type | Deep pool | Deep pool | Flooded forest and shrubland | Deep pool | Deep pool |
| Size and depth in dry season | 140 ha, 30 m | 120 ha, 30 m | 200 ha, 36 m | 40 ha, 60 m | 1.2 ha, 70 m |
| Year established | 2012 | 2012 | 2012 | 2014 | 2014 |
| Number of villages (CFi) involved in management | 2 | 2 | 5 | 2 | 2 |

Sources: project workshop reports, 2011, 2014; candidate site profiles 2011, 2014.

was located on an islet in the middle of the Mekong River. Nearly 60 % of the households were considered "very poor", with small or no farmland and no livelihood alternative to fishing. Initially in 2012 the width of the buffer zone accessible for the villagers to catch fish had been set at 50 m from the bank of the islet towards the center of the FCZ. By early 2014 many villagers claimed the buffer insufficient for supporting their livelihoods. With facilitation of a Commune Chief, the buffer zone was widened to 100 m—deemed a fair compromise—after a series of negotiations over a period of several months. The FCZ committee resumed its operation after all parties agreed to the new buffer zone arrangement (WorldFish, 2016b).

### 4.3. Perceived conservation outcomes of the FCZs

Stakeholder perception of the fisheries resource status varied depending on individuals, and the location, season, and the fishing methods employed. However, fishers involved in the catch monitoring and/or the FCZ patrolling reported positive outcomes using specific indicators. Many of the respondents described an increase in fish abundance in the river as "*it's easier to catch fish now than before*" and "*it takes less time fishing to catch the same amount of fish*". Another widely stated outcome was the reappearance of larger, high-value predator fish in and around the FCZs, that had become rare in the catch prior to the project intervention.

As shown in Table 4, the local community representatives involved in the management of the 3 FCZs reported during the qualitative surveys in 2013 the reappearance of large predator fish in the no-take zones and the sighting of Irrawaddy dolphins, a top predator, and was endangered in the Mekong River. An elderly fisherman who lived next to the *Kambor* FCZ and participated in the fish monitoring provided his overall reflection in 2015: '*When the fish are protected, there are noticeably more of them within the conservation zone. When the water in the Mekong River rises, fish from the conservation zone spread into other areas, allowing me and other fishers to increase fish catch*' (the project KII notes, 2015).

The perception of individual fishers was supported by the observation of fish traders who collected fish from the fishers in the Ramsar site and sold to other regions in Cambodia and to Lao PDR. They noted that *Krabei* (*Bagarius bagarius* and *B. Yarelli,* goonch catfish) became abundant although in smaller sizes, and to a lesser extent *Kes* (*Phalacronotus micronema* and *P. Bleekeri,* sheetfishes), *Klaing Hay* (*Belodontichthys truncatus,* sheatfish), *Chhveat* (*Pangasius macronema,* shark catfish), and *Kya* (*Hemibagrus wykioides,* Asian redtail catfish) also increased in the river. The respondents considered these large species to be an indicator of resource recovery (WorldFish, 2017).

Comparison of fish catch records from the same monitoring period in 2012–2013 and 2014–2015 appeared to support some of these observations while inconclusive of others. Table 5 shows the increased occurrence of *Phalacronotus* species, *Pangasius macronema*, and *Hemibagrus wyckioides* in the catch records while the occurrence of *Bagarius* and *Belodontichthys* species slightly decreased. Due to the limited sample of each species reported in the catch records, and the wide range in the size of individual specimens, it was not possible to interpret these results further.

*Trey riel* (*Henicorhynchus siamensis*, Siamese mud carp), a small migratory fish species important for local food security and livelihood, increased in terms of both the occurrence and the share of weight in the recorded fish catch. The abundance and the catch of this fish was known to fluctuate widely, and typically peaked in a few months during the dry season when the fish migrated. The catch records of *Henicorhynchus siamensis* from the August 2012 to May 2013 monitoring period were few and were able to detect "peak" catch levels (> 5 kg/fisher/day) occurring only at the *Kol 46* FCZ in the month of April 2013. Other catch records were all less than 2 kg. On the other hand, the August 2014–May 2015 monitoring data showed moderate catch levels between 3 and 6 kg occurring at both the *Kol 46* and the *Kambor* FCZs throughout the dry season of January to May 2015, with peak catches in March 2015. The sustained level of *trey riel* catches, to which every fishing household relies on for food security, likely influenced the stakeholder perception of the resource status in the latter monitoring period.

The prevalence of illegal fishing in the FCZs, especially the use of destructive fishing methods, was considered as the biggest threat to the fish in the Ramsar site and thus was commonly used by the local stakeholders as an interim indicator of conservation outcome. The reduction in illegal fishing was an important direct outcome of the patrolling effort, reported by all 3 FCZ management committees at the project reflection workshops in 2012 and 2013. While the patrolling significantly deterred illegal fishing, it was impossible to eliminate it. The *Kol 46* FCZ initially faced violent retaliation from illegal fishers who burned the fishing boat belonging to a patrol team member. Furthermore, the recovery of fisheries was followed by intensified and more sophisticated illegal fishing a few years later at the *Kambor* FCZ. Illegal fishers targeted the FCZs even more than before, after learning that fisheries had recovered in these areas (WorldFish, 2016a). This resulted in the needs for more frequent and coordinated patrolling and increased cost of patrolling.

**Table 4**
Perceived conservation and livelihood outcomes of the first 3 fish conservation zones (FCZ). The 2 newer FCZs not included because of shorter implementation period.

| Indicators | FCZ name | | |
|---|---|---|---|
| | *Kol 46* | *Kambor* | *Preah Sakhon* |
| Conservation outcomes | | | |
| Illegal fishing | 80 % reduction[a]. Incidents of retaliation against patrol team members at an early stage[c]. | Reduction in electric gear and explosives[a]. Illegal boats returned in large numbers[d]. | 70 % reduction[a]. Increased confrontation with illegal fishers[d]. |
| Fisheries resources | Increase in fish size and biomass, including large predator species[b]. | Stable, or slight increase in fish biomass, including large predator species[b]. | Increase in fish biomass and reappearance of large predator species[b]. |
| Rare and endangered species | Reappearance of Irrawaddy dolphins and Jullien's golden carp[b]. | Reappearance of Irrawaddy dolphins and giant catfish[b]. | Reappearance of Irrawaddy dolphins[b]. |
| Livelihood outcomes | | | |
| Fishing effort and cost | Reduced effort; easier to catch same volume of fish in less time. Added travel cost to alternative fishing ground for some fishers[b,e]. | Reduced effort for subsistence female fishers using small gear. Added initial cost of modifying gears to access the buffer zone[b,e]. | Reduced effort; easier to catch same amount of fish in less time[b,e]. Seasonal migrant families having to move fishing camp elsewhere[b]. |
| Fish catch | Increased or stable catch; return of high-value fish in the catch[b,e]. Complaints from some non-resident fishers of reduced access to fishing ground[e,g]. | Safeguarded fishers satisfied with their catch only after widening the buffer zone[e,f]. Less catch for other fishers due to reduced access to fishing ground[e,g]. | Increased or stable catch; return of high-value fish in the catch[b,e]. |
| Other livelihood activities | More time available for farming and other activities, but benefit was felt more by full-time fishers than occasional fishers[e,f]. | More time available for farming, but very few other livelihood options available on the islet[e,f]. | More time available for farming and increased income from farming[e,f]. |

Sources: a. reflection workshop reports (2012, 2013); b. FGD and KII notes (2013); c. WorldFish (2013); d. reflection workshop report (2015); e. FGD and KII notes (2015, 2016); f. social safeguard updates (2015, 2016); g. WorldFish (2016b).

**Table 5**
Frequency and average weight of selected commercially-important species reported in fish catch monitoring at the *Kol 46* and the *Kambor* FCZs.

| Scientific name | Local name | Common name in English | Aug 2012–May 2013 | | | Aug 2014–May 2015 | | |
|---|---|---|---|---|---|---|---|---|
| | | | Occurrence in catch record | Share of total catch weight | Average weight of fish (kg) | Occurrence in catch record | Share of total catch weight | Average weight of fish (kg) |
| *Bagarius bagarius or B. yarelli* | *Krabei* | Devil catfish, goonch | 3.97 % | 2.12 % | 0.76 (± 2.51) | 2.92 % | 3.37 % | 1.10 (± 0.91) |
| *Belodontichthys truncatus* | *Klaing Hay* | Truncated sheatfish | 1.19 % | 0.89 % | 0.93 (± 0.44) | 0.76 % | 0.90 % | 1.0 (± 0.91) |
| *Hemibagrus wykioides* | *Kya* | Asian redtail catfish | 3.17 % | 2.12 % | 1.96 (± 1.51) | 12.53 % | 7.08 % | 0.75 (± 0.26) |
| *Labeo chrysophekadion* | *Ka'Aek* | Black shark minnow | 4.78 % | 6.93 % | 0.94 (± 1.39) | 7.99 % | 7.02 % | 0.86 (± 0.77) |
| *Pangasius macronema* | *Chhveat* | Shark catfish | 2.38 % | 1.57 % | 0.11 (± 0.08) | 5.18 % | 1.66 % | 0.16 (± 0.28) |
| *Phalacronotus micronemus or P. bleekeri* | *Kes* | Sheatfish | 0.79 % | 0.54 % | 0.56 (± 0.05) | 4.54 % | 4.08 % | 0.74 (± 1.16) |
| *Henicorhynchus siamensis* | *Riel* | Siamese mud carp | 3.17 % | 11.80 % | 0.02 (± 0.09) | 24.19 % | 40.16 % | 0.014 (± 0.004) |

Source: the fish catch monitoring data collected by the project in 2012–2015. A total of 49 species recorded in the sample of 90 daily catch records from the period 2012–2013; 39 species in the 621 daily records from the period 2014–2015. The data from other 3 FCZs not included in this analysis because of the difference in survey period.

### 4.4. Perceived livelihood outcomes of the FCZs

The local stakeholder perception of livelihood outcomes was mixed (Table 4). During the qualitative surveys in 2013 and 2015, positive outcomes in terms of reduced effort required to catch the same quantity of fish as before was reported at the *Kol 46* and the *Preah Sakhon* FCZs. Increased income from the return of high-value fish in the catch was also reported from these two FCZs. At the *Kambor* FCZ, the FCZ operation was suspended in early 2014 due to the complaints from a local village of the restricted access to and the declined catch from the fishing ground. Although the preferential fishing access granted to the poor and vulnerable households was deemed satisfactory after the buffer zone was widened in late 2014, no clear positive livelihood outcome was reported thereafter.

The cost of traveling to alternative fishing grounds, or changing the gear, was initially reported as a negative outcome at all 3 FCZs during the monitoring survey in 2013. Some of the fishers who frequented the *Kol 46* and the *Kambor* FCZs prior to their designation as no-take zones in 2012 continued to express their frustration with the reduced access to the productive fishing grounds during the surveys in 2015 and 2016. No such complaints were reported from the *Preah Sakhon FCZ*, probably because there was no adjacent village solely relying on this area for fishing.

An indirect indicator of the livelihood outcome of the FCZs was the time it took to catch what the fishers considered as "enough" fish each day. Reduction in the time spent on fishing meant that they had more time available for other livelihood activities, such as farming and livestock, which made up household income. However, this benefit was not felt equally among all households. Some households who had been more specialized in fishing compared to other livelihood activities prior to the establishment of FCZs benefited most from the time saved from fishing. Others who had few livelihood alternatives other than fishing simply increased the fishing effort to capitalize on the recovery of fisheries in the buffer zones. Those who were involved in fishing only occasionally reported an increase in the time and cost of having to go fishing elsewhere (the project KII notes, 2016).

We were not able to triangulate these qualitative results with quantitative household income and labor allocation data, as conducting such a detailed survey was beyond the scope of our project. In a typical rural household in Cambodia, each family member engaged in multiple livelihood activities seasonally in order to maximize overall household income. Much of the fish catch and family farm crops were retained for home consumption. Hence comparing the annual income contribution from fishing from one year to another would not necessarily reflect their livelihood conditions.

An average daily fish catch per fisher (in kilograms) was the most commonly-used indicator by the survey respondents when asked to describe how their fishing livelihood was affected by the FCZs. An earlier interview of 40 fishers resulted in mixed opinions of the level of fish catch (the project KII notes, 2013). A follow-up interview of 37 fishers in 2015 found fish catches to have been relatively stable in the preceding years, despite natural fluctuations in the fisheries resources (the project mid-term evaluation report, 2016). Some fishers reported that the increase of high-value fish in the catch and the reduced cost of fishing resulted in an increased net income from fishing (the project FGD and KII notes, 2015, 2016). The findings of an external evaluation of the project (Estepa, 2017) were also consistent with the results above. Twenty-six local fishers who participated in the FGDs reported daily fish catches at 2 kg on average—what they considered acceptable for daily catch as a viable livelihood option—and peak catches during fish migration season, reaching 10 kg per day or more.

Because the fish catch had been widely perceived as declining prior to the project intervention, the surveyed fishers considered the sustained catch levels as a successful outcome by itself. A group of fishers protecting the *Preah Sakhon* FCZ stated: '*without conservation, fish would have been long gone because of illegal fishing* (the project KII notes, 2015). The respondents to the project evaluation also reported they did not observe much difference in the catch in the previous five years, even with the no-take FCZs, and despite various threats to fisheries resources, such as environmental degradation and hydropower development (Estepa, 2017).

The fish catch records at the *Kol 46* and the *Kambor* FCZs were generally consistent with the perception of sustained fish catch levels. Table 6 shows summary statistics of the catch records from the two monitoring periods. During the 2012–2013 reporting period, the

**Table 6**
Daily fish catch per fisher in the *Kol 46* and the *Kambor* FCZs (kilograms).

| Monitoring period | Average | Median | Minimum | Maximum |
|---|---|---|---|---|
| Aug 2012–May 2013 (n = 90) | 3.06 (± 2.49) | 1.73 | 0.28 | 11.67 |
| Aug 2014–May 2015 (n = 621) | 2.34 (± 1.59) | 2.00 | 0.10 | 11.20 |

Source: the fish catch monitoring data collected by the project in 2012–2015.

average daily catch per fisher was recorded at 3.06 kg (± 2.49), while the average in the 2014–2015 period was 2.34 kg (± 1.59) and the distribution did not differ significantly from the 2012 to 2013 period (Mann-Whitney $U = 26{,}400.5$, $P > 0.05$).

## 5. Discussion

### 5.1. Balancing management objectives and resolving conflicts

This case study demonstrated some advantages of adaptive co-management, supporting previous arguments (Berkes, 2007; Ostrom and Cox, 2010). With the flexibility in setting the management rules and the sufficient time to make decisions, the local stakeholders were able to negotiate between conservation and livelihood objectives at different stages of the management process, to make critical decisions jointly, and to resolve conflicts. They adjusted the management rules to balance various outcomes of the FCZs, taking into consideration their own capacity to implement these decisions. On the other hand, the PAR approach to project M&E resulted in the tendency to overgeneralize individual findings and experiences into common elements alone. A more structured approach for elucidating each decision-making process, and for supporting cross learning and peer-to-peer assistance among the FCZs, would benefit future expansion of the FCZ network.

The lessons learned were not uniform across all sites. The conservation of the *Preah Sakhon* FCZ exemplified logistical challenges and high cost of protecting a remote and vast area, in exchange of notable conservation outcomes with minimal negative social impacts. The *Kambor* FCZ demonstrated the need for careful negotiation and conflict resolution among various stakeholders every step of the way in the context of high resource dependency. The root cause of the conflict was severe poverty in the local community, and the heavy reliance of both local and external fishers on this site for their income and livelihoods. On the other hand, the community members leading the management of the *Kol 46* FCZ attributed their relative ease in resolving internal conflicts to the moderate wealth of the community, enabled by several other livelihood options (the project reflection workshop report of 2013). Having prepared site-specific profiles of poverty, livelihoods, and stakeholders, the project team was able to anticipate, and respond to, these unique challenges faced by each FCZ.

Some issues were resolved through the adaptive co-management process while others persisted. Although the patrolling significantly deterred illegal fishing at all the sites, it was not able to eliminate it. The recovery of fisheries was followed by intensified and more sophisticated illegal fishing, targeting the FCZs even more than before (WorldFish, 2016a). The problem of illegal fishing extends beyond the fisheries sector, as it is perpetuated by the weak judiciary system as well as persistent poverty. The patrol teams consisting of local volunteers felt powerless against the resourceful criminal groups that sponsored illegal fishing, being threatened by retaliation. A more systematic understanding of, and concerted approach to combating illegal fishing at all levels of government and across agencies is needed to leverage the positive outcomes resulting from conservation (Sander et al., 2014).

Relatively small number of individuals among the local stakeholders drove much of the obstacles and the achievements in co-management, confirming the findings of previous studies (e.g., Pomeroy et al., 2011; Gutiérrez et al., 2011). Hindrances were caused by the extreme poverty of some local households or undesirable behaviors of others driven by self-interest. On the other hand, it was common across all the sites that a few highly-motivated individuals championed conservation and persisted in the effort despite the obstacles. Understanding of human behavior in, and the systematic application of this knowledge into co-management practices, would improve its effectiveness, as was previously proposed (Aswani et al., 2018; Turner et al., 2016).

### 5.2. Role of FCZs in fisheries management

Our project demonstrated an area-based conservation approach as an instrument for fisheries management in tropical river systems, which was designed and implemented by local resource users. With the relatively simple conservation design based on their own knowledge, the resource users were able to reduce fishing pressure on key fish habitats over the course of several years. Their perception of the FCZ approach as yielding positive conservation outcomes across the first 3 sites led to the creation of 2 additional FCZs within the Ramsar site. Particularly important was the sustained fish catch and the recovery of some high-value fish species in the catch over the years, despite the earlier prediction of fisheries declines due to rapid hydropower development in the region (Dugan et al., 2010; IFReDI (Inland Fisheries Research and Development Institute), 2012; Ziv et al., 2012), and the documented declines in the high-value fish in other parts of Cambodia (Chan et al., 2020; Ngor et al., 2018).

These findings are encouraging as interim evidence of the efficacy of FCZs; however, we were not able to quantitatively verify the stakeholder perception of the fisheries status using the catch monitoring data due to its limited scope in sampling and duration. We also acknowledge that our results are rather localized, and the interannual variability in hydrology and local environmental conditions may have influenced the changes in fish abundance and species composition more strongly than the level of protection from fishing pressure, as indicated by other studies on fish sanctuaries in tropical river systems (Keppeler et al., 2016; Fiorella et al., 2019).

Further refinement of the FCZ approach, based on the lessons from this project and others in the region, and more rigorous evaluation of their performances, are needed. The identification of other dry season refuges or spawning areas of migratory fish, the minimum size requirement for a FCZ, and the design of an effective buffer zone to allow localized fishing access, could reduce the cost of protecting no-take zones and the burden on the local communities.

Our study was constrained by the difficulty in assessing the condition of diverse and seasonally dynamic tropical river fisheries. The status of Mekong fisheries in Cambodia, and the factors driving its changes, are still a subject of debate among experts (Ngor et al., 2018; Halls and Hortle, 2021). Fundamental challenge lies in the limited temporal and geographic coverages of existing monitoring programs, and difficulty in the analysis of the data that exist. Simple yet scientifically robust approaches for tropical freshwater fisheries monitoring and assessments are needed. Various methods have been introduced to several locations in the Mekong Basin (Elliott et al., 2019; Freed et al., 2020; Loury et al., 2019); however, lack institutional mechanisms to support their long-term implementation. Periodical assessments of indicator species, rather than the entire multi-species fisheries in the Mekong, would facilitate the performance evaluation of specific management measures locally.

### 5.3. Institutional sustainability of adaptive co-management

Having documented the project implementation over 6 years, we note that balancing multiple objectives of fisheries co-management over time, and ensuring the overall outcomes remain positive, requires long-term commitment of all stakeholders involved. Regular monitoring, attentive decision-making, and timely interventions at critical junctures are necessary for encouraging desirable human responses while avoiding, and responding to, undesirable ones. How to sustain co-management institutions through long-term funding, after the life of external donor assistance, has been the most pressing challenge facing all CFi in Cambodia (Kurien, 2018), if not most natural resource co-management institutions around the world (Cundill and Fabricius, 2010; Plummer et al., 2012).

At our study site, the adaptive management process relied heavily on external financial assistance and facilitation. The cost of monitoring and

evaluation, including the stakeholder meetings and external facilitation, was almost entirely borne by the project (the project progress report, 2016). Community-based fish conservation requires, at the very least, some cash revenue for the local communities to cover the cost of patrolling (e.g., gasoline). In Cambodia, policy revisions are in progress to broaden options for CFi groups to generate their own revenue through various fee collection schemes and business ventures, and to gain structured access to local government funding (Kaing et al., 2021). Meanwhile, support from donors and NGOs continues to be important. Further investigation into how to build institutional and financial sustainability in natural resource co-management is needed.

## 6. Conclusions

In this paper we offered critical reflection on an adaptive co-management of fish conservation zones (FCZs) in the Mekong River and its social-ecological outcomes as perceived by local stakeholders. The following key lessons from our case study are broadly applicable to other countries and geographies where natural resources and local livelihoods are closely interconnected. Adaptive co-management provided an effective mechanism for the local stakeholders to: negotiate between conservation and livelihood objectives at different stages of the implementation; make critical decisions jointly; and resolve some conflicts, if not all. The degree of difficulty in conflict resolution varied from site to site, and was mainly a function of the dependency of local communities on the protected resources, the prevalence of severe poverty in the area, and the availability of livelihood options other than fishing.

Initially a "no go" decision was taken for the sites where the potential negative impacts of conservation on local livelihoods were perceived as high. Growing stakeholder perception of the FCZs as yielding both positive conservation and livelihood outcomes motivated the local communities to push the balance further towards conservation, even for other locations where the potential for resource user conflicts was high. In a context of low regulatory capacity within the government system, co-management of FCZs facilitated the application of basic conservation measures in fisheries management led by local fishers. We argue clear recognition by the local stakeholders of the achievements and the fairness in the management of FCZs, facilitated through participatory approaches, can improve their acceptance of conservation rules and in turn enhance their effectiveness. However, long-term mechanisms to support these community initiatives technically and financially are needed.

Our assessment of the FCZ outcomes relied on stakeholder perceptions and was therefore limited. Simple yet scientifically robust approaches for tropical freshwater fisheries monitoring and assessments are needed. We also note social-ecological systems rest on fragile balance between natural resources and human actions, and do not exist in isolation. Broader policy and environmental changes could easily destabilize the dynamics in the future and thus deserve further research attention.

## CRediT authorship contribution statement

**Yumiko Kura:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Kosal Mam:** Investigation, Data curation, Writing – original draft, Project administration, Funding acquisition. **Seila Chea, Dyna Eam:** Investigation, Data curation. **Kaitlin Almack:** Investigation, Data curation, Writing – original draft. **Hiroe Ishihara**: Writing – review & editing, Supervision.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Yumiko Kura, Kosal Mam, Seila Chea, Dyna Eam reports financial support was provided by Critical Ecosystem Partnership Fund. Yumiko Kura, Kosal Mam, Seila Chea, Dyna Eam reports financial support was provided by Fondation Ensemble. Yumiko Kura reports financial support was provided by Ministry of Foreign Affairs of Japan.

## Data Availability

Data will be made available on request.

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